THE ECONOMICS OF SINGLE
vs.
MARRIED-PAIR TRANSIT CARS

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June, 1988

OP-x88131

I. STATEMENT OF PROBLEM

The question this paper tries to answer is whether or not electric multiple unit rail cars (EMU's) should continue to be purchased as "married pairs" or should be purchased as "singles" as they once were. The question arises because of daily problems encountered with married pairs by rail car maintenance organizations. The question is often argued among managers responsible for placing new EMU cars into service and then maintaining and overhauling them. The problem was experienced by this writer both as a carhouse foremen on the Boston M.B.T.A. Red Line and as Chief Mechanical Officer at Philadelphia's S.E.P.T.A. Evidence of interest in the question's answer is given by the four different EMU maintenance groups that provided data and information when asked to.[1]

The question of purchasing single vs married pairs can be put as a conventional investment decision: Which "machinery" configuration is the best investment choice for the approximately one billion dollars of EMU cars and shops purchased yearly? Although the methodology for answering this question is well known, the public transit industry very rarely employs a discounted cash flow analysis. When it does, the cash flow structure rarely reflects the physical reality it is to model.

It may be useful, now, to define what is an "EMU", a "single", and a "married pair" for those not familiar with the terms. An "EMU" is what is often called a subway car, metro car, rapid transit car, electric commuter railcar, etc. It is propelled by electric motors; fed by third rail direct current/catenary wire direct current, or catenary wire high voltage alternating current. These cars run in trains, typically from four to ten cars long, with all cars having propulsion motors operated in unison from one car's control stand. There are apparently endless variations of the technology, but most fall into two varieties: third rail DC, high platform rapid transit; or catenary AC, mixed platform commuter railroad. LRV's, DPM's and streetcars are not included, although they sometimes run in a "multiple unit" mode. "Motor-trailer" combinations are also not included, although the methodological framework below readily permits such an analysis, as it does of the newly proposed "triples."

A "single" car carries all the components to make it a complete train by itself, such as cabs at both ends, propulsion motors and controls, compressors, batteries, ATO/ATC systems, and so on. The possible minimum size train is one car, and the smallest increment of train capacity is one car. Since there are cabs at both ends, reversing direction is easily done.

A "married pair" mechanically joins two singles together. Usually a coupler is removed at one end and a permanent drawbar is attached, and automatic electric/air couplers are replaced with cables and hoses. The cabs at the permanently coupled ends are removed and the empty space filled with seats and standee floor space.

One car has its air compressor system removed. The other car will pump air to it. The air supply car has its low voltage power supplies, such as batteries, convertor, and motor alternator set removed. It's mate-for-life will supply it with this power. Now other redundant items can be removed, such as toilets, pantographs, and ATO control lockers.

Up until the early 1950's, EMU cars were purchased as singles, often towing unpowered "trailers" if horsepower was not a constraint. By the mid-1950's married pairs became the predominant style of purchase. Where the rail line wished to run trains with odd numbers of cars (one, three, five), mixed orders of married pairs plus singles were sometimes ordered. By the 1970's, virtually all cars ordered were married pairs. All newly constructed systems (WMATA, MARTA, Metro Dade, Baltimore) specified married pairs.

The economics that justified the shift to married pairs are:

- maintenance savings by eliminating one set of batteries, one motor-generator, one air compressor, one toilet (optional), two complete cabs, and one pantograph (on some cars) for every two cars;

- eliminating capital costs of purchasing on all the foregoing components;

- reducing downtime by reducing the number car components;

- increasing the available floor space in each car, thereby, reducing the capital costs by reducing the number of cars needed.

However, in 1980 some operators who had purchased married pairs found reason to return to singles as problems with married pairs came out. These included SEPTA, the NYCTA, and BART. The problems noticed are:

- increased capital costs because fleet requirements increased. Downtime rose because when a car broke down, its mate in marriage had to be removed from service, too;

- increased capital cost because shop bays and shop machinery had to accommodate cars "twice" as big. For example, every hydraulic truck-and-body hoist needed a second complete hoist installation to carry the cripple car's mate;

- increased transportation line costs as the increment of train capacity doubled.

Whether or not the problems justify returning to purchasing singles is the question now to be answered.

II. METHODOLOGY

The methodology employed to answer the question is a straightforward discounted cash flow analysis. A base case is chosen: purchase all married pairs. Then an alternative case is selected: buy conventional singles. Parameters, such as the cost of capital or out-of-service failure rate are set. Then the cash flows are calculated for important components in the cost equation. Other components are not calculated because of computional difficulty. The cash flows are discounted and a net present value obtained. The magnitude and size of the net present value argues for the base or the alternative course of action. The net present value is then annualized. This bounds the maximum value of the cost components whose values were not computed.

Certain parameters then are changed to determine how the net present value changes, i.e. the parameters are treated as assumptions. The results are compared and conclusions suggested.

Finally, an alternative configuration is evaluated. This configuration is the single-cab single. These cars are starting to slowly appear and could represent an optimum configuration.

The methodology above is nothing unusual or sophisticated. It appears, however, not to be generally used in the transit industry to make decisions. There is one unusual aspect of our analysis: Shop construction and actual maintenance costs are included.

III. FORMULATION OF COST

A simple aritmetic equation is used to generate the net present value (NPV). Basically, the NPV, overall, equals the present values between singles and married pairs for:

- the difference in overall purchase cost of the car fleet
- the difference in maintenance costs
- the difference in inventory size costs
- the difference in shop construction costs
- the difference in transportation operation costs

Purchase cost of the car fleet is a function of the number of cars needed to carry a given peak period load, allowing for scheduled maintenance and repair spares, plus the cost of providing the additional components on singles. Two peak hour requirements were examined: 80 cars and 300 cars. 80 cars is a small rapid transit line; 300 cars is a fairly large operation. Both fleet size requirements are evaluated to determine the effect of economies of scale on the outcome.

The cost of the married pairs are taken to be $1.3 million each car for production runs under 100 cars and for $1.1 million each car for runs over 200 cars. Wide scattering of car costs is seen when plotting price against quantity or against complexity. The figures used here are believed to be reasonable judgements of the cost of a large, state-of-the-art rapid transit car.

The allowance for cars requiring maintenance and repair work is a key figure. Scheduled maintenance investment, both cars and shops, are believed to be the same for either singles or married pairs.[2] However, unscheduled repair car requirements are not. A failed single car requires shopping a single car, except for trainline problem diagnosis. A failed half of a married pair requires its mate to be shopped with it. Indeed, it also requires an addition to the repair shop so that the mate can be parked next to it.

Proponents of married pairs, and longer sets, claim that this is not a valid requirement for fleet planning. They claim that with proper maintenance and new equipment designs, passenger rail cars can exhibit the same reliability as, say, commercial airlines do. However, most thoughtful railcar maintenance managers find the proposition that nothing will break down as their only entertainment in an otherwise bleak professional existence.

As a base case for the rate of failure shopping, data provided by the Delaware River Port Authority's PATCO was used for 600VDC third rail cars. PATCO was chosen because it's failure rate represents one of the better achievable, i.e. PATCO's situation is the closest to the argument that with intelligent maintenance, nothing should break down. Historically, PATCO's maintenance remains among the best. Accurate records have been kept from the beginning, mechanics have been trained and are disciplined, shops are modern, and management has been open-minded, innovative, and educated. The budget/political process is more stable than others. In other words, PATCO is as good as one may expect to get over the long run.

The PATCO fleet was also chosen for its configuration. The singles date from 1969 and have all been heavy overhauled since. The married pairs were built in 1982.[4] In other words, the cars are middle-aged. The bodies are stainless steel and the trucks are welded. Propulsion control is switched rheostatic governed by analog electronics. The cars are equipped with an effective ATO system. In general, the study fleet is a modern car of moderate complexity, middle-aged but well maintained.

Out-of-service rates, calculated from PATCO MDBF figures, are 5.1% for married pairs and 5.3% for singles.

Maintenance costs were derived partly from PATCO data and partly from independent estimates. Three specific sets of cost differences were calculated. One cost difference set is maintenance stemming from the difference in the number of cars required. This is a cost "per car." The cost per car is non-linear below 80 cars and approximately linear from 80 to 300 cars.

Another cost difference set is the cost for annual maintenance of the additional components carried on a single. A fleet of singles has about twice as many air compressors, cabs, etc. as married pairs. The third maintenance cost difference set is the overhaul cost for additional components. Instead of an annual figure, this overhaul cost occured every five years.

The difference in spare parts inventory capital cost results from the difference in the number of cars required. A figure was calculated, based upon current industry practice, for the base case. The inventory investment then changed according to the square root of the change in car fleet size. It is assumed inventory levels will not change significantly over time for a well maintained fleet as most dollar value of inventory is in major spares, which must be purchased with the new cars.

The difference in shop construction costs varied either with the failure rate or with the fleet size. Engineering estimates were obtained of construction costs for various types of shop facilities. The number of hoists and wheel trueing plant are a function of fleet size. Raised rail repair spots are a function of failure rates. The primary cause of cost differences is the fact that a given repair facility ("spot") in a shop is about twice as long for a married pair as a single. A car length of seventy-five feet is used.

The cash flow analysis did not assume an ownership of plant or rolling stock permitting the use of a depreciation tax shield. The introduction of this tax advantage might be warranted in the future as public rapid transit and commuter rail operators may lease shops and cars, instead of grant funded purchase aquisitions.

The difference in transportation costs is not calculated. This cost is so complex it requires another study to analyze. The NPV of the above costs, annualized, can give one a maximum or minimum value for this cost, however.

IV. RESULTS

The results of the various analyses are shown in Tables I, II, and III. These tables were obtained by using the married pair configuration as the base case, and computing the difference in cash flows that occur when one changes to single cars. Where the cash flow extends into the future, it is discounted by 10% to obtain a present value.[3] Married pair is employed as the base case because it is the prevelant practice today.

The net present value is the sum of the discounted cash flows. It is annualized over a twenty-five year period to yield a figure to compare to cash flows not included in the analysis.

Table I suggests that for small schedules using large cars, married pairs are of no significant advantage. While the net present value is positive, it is only so by an amount probably less than the error in the cost estimates. The net present value is less than 2% of the cost of the cars and spare parts. If the transportation costs of using married pairs is greater than $700 a day, the "gain" disappears.

TABLE I: 80 CAR SCHEDULE
$ in 000's
75' Rapid Transit Car

		Married Pairs	Single Cars	Difference
(1)	Fleet Size	92 cars	87 cars	(5 cars)
(2)	Change in shop space	-----	(13,000 sq.ft.)	(13,000 sq.ft.)
(3)	Cost of Cars	$119,600	$123,300	$ 3,700
(4)	Cost of Inventory	$ 16,900	$ 16,400	$ 500
(5)	Cost of Change in shop space	-----	$ (1,400)	$ 1,400
(6)	Present Value of Maintenance Costs	-----	$ 600	$ (600)
(7)	Net Present Value	-----	-----	$(2,400)
(8)	Annualized NPV	-----	-----	$(260/yr)
(9)	Net Present Value At 0%	-----	-----	$(2,200)

The gain certainly disappears if the out-of-service failure rate is anything less than the best. A 1% increase in this failure rate reduces the present value of utilizing the married pair configuration to only $780,000, or ½% of the cost of the cars, as shown in Table III. A 2% increase make the NPV negative. It will be instructive to return to the problem of out-of-service failure rates later.

Table I basically shows that, while singles require fewer cars to be purchased, each car costs far more because of the redundant components needed. However, the component investment savings of married pairs are partly offset by the increased shop construction investment.

Fewer cars means less inventory. Although singles add the redundant components to the spare support requirements, there are fewer varieties. Component system manufacturers and carbuilders persist in building major component assemblies that are <u>not</u> interchangeable. A propulsion controller assembly on the "A" car typically will not go on the "B" car without modification.

Maintenance costs are less for married pairs. Although our example has five fewer cars to maintain, there are forty more air compressors, battery sets, cabs, etc. to maintain.

For large schedule requirements, say 300 cars, it is assumed that every seat and every square meter of standee space count. For this service, eight and ten car trains on short headways are the norm and ridership demand approximates capacity. (Else why run so many cars?) Table II strongly argues that married pairs are far more cost effective than the standard car configuration. The net present value is $48.5 million, or 12% of the initial investment in cars and spare parts.

In this operations scenario, the additional married pair cars needed for out-of-service repairs are counterbalanced by the additional standard single cars needed to compensate for the loss of car floor space. And since single cars cost more than married pairs, the car fleet investment for standard singles far outweighs the investment for married pairs.

TABLE II: 300 CAR SCHEDULE
$ in 000's
75' Rapid Transit Car

	Married Pairs	Standard Singles	Difference Singles	Single Cab Singles	Difference
Fleet size	346 cars	352 cars	+6 cars	329 cars	- 17 cars
Change in shop size	------	(-32,000) sq. ft.	(-32,000) sq. ft.	(-33,000) sq. ft.	-33,000) sq. ft.
Cost of cars	$380,600	$425,600	$(45,000)	$381.300	$ (700)
Cost of Inventory	$ 32,800	$ 33,100	$ (300)	$ 32,000	$ 800
Cost of Change in Shop size	-------	$ 2,700	$ 2,700	$ 2,800	$ 2,800
Present Value of Maintenance Costs	-------	-------	$(5,800)	-------	$ 2,100
Net Present Value	-------	-------	$(48,400)	-------	$ 5,000
Annualized NPV	-------	-------	$(5,300)	-------	$ 550
Net Present Value at 0%	-------	-------	$(57,300)	-------	$13,500

The additional repair shop required by married pairs is not as significant a factor as it was for the 80 car schedule. Some of the additional plant does not vary with the range of fleet size being investigated here. For example, only one wheel truing machine is needed for either 80 cars or 300 cars. In effect, economies of scale mitigate the repair problems of married pairs.

Maintenance costs also favor married pairs. There are fewer cars and fewer components on each car.

It should be noted that there are EMU car types that do not completely admit of the above arguments. These EMU's are vestibule equipped cars running in the Northeast Corridor, such as NJT's Arrow III or SEPTA's Silverliner IV. These cars have no cabs: The control stands are built right into the vestibule. No capacity is gained by marriages on the Silverliner IV, and the only capacity gain on the Arrow III's is the redundant lavatory.

An examination of Table III shows, however, that the married pair is still subject to the problem that its financial and operations benefits erode rapidly as out-of-service failure rates rise. A 1% increase still leave married pairs with an undeniable present value. But the analysis that generates this value, i.e. my analysis, is biased in favor of married pairs.

TABLE III
WHAT HAPPENS IF FAILURE RATE RISES BY 1% OF FLEET SIZE

Car Configuration and Schedule	New Fleet Size	Increase in Fleet Size	Spare Ratio	Change in N.P.V.	New N.P.V
80 Standard Single	88	1	10%	$1,610	$(780)
80 Married Pair	94	2	15%		
321 Standard Single	355	3	10%	$7,300	$(41,200)
300 Married Pair	354	8	15		
300 Single cab single	332	3	10%	$7,500	$(12,400)

That bias originates in the use of a mean failure rate. "On the average, only 5% of our cars need repair." However, much out-of-service time is the result of non-random failures, such as repair part quality failure, snowstorms, parts shortages, and so on. These sudden epidemics have their effect doubled by the married pair. New car deliveries are especially vulnerable to this problem. Good planning for weather problems and good quality control of material and repairs can minimize the vulnerability of married pairs to surges in bad-order count. But the vulnerability remains.

However, among all alternatives for a 300 car schedule, the best net present value is found for the single cab single car. The single cab requires the smallest fleet to meet capacity requirements because it exhibits both the lower repair requirements of standard singles and the higher passenger capacity of married pairs.

Single cab singles still require about the same gross purchase investment of married pairs; again, the trade-off is between cost of each car and the number of car purchased.

The single cab singles require less shop investment, less inventory, and less maintenance expenditures. Recall that the single cab eliminates one of the two redundant cabs, along with 5% of the car fleet.

Single cab singles have one important drawback: They cannot be flexibly run as single car trains unless extensive investments are made in turning loops. For that reason, no analysis was made of their present value compared to married pairs for the 80 car schedule scenario, i.e. where one may expect the lighter ridership and a need for single car trains. However, if it is policy to never operate a single car train, then cab singles are probably the lowest cost investment here.

A strong reason to prefer single cab singles is they are not sensitive to the discount rate, i.e., the cost of capital. The trade-off is not between present investment and future operating cost cash streams because single cab singles require both less initial investment and less future operating costs.

Despite this, one cautions against a sudden change in new car purchase configurations. There are reasons not to adopt singles:

1. One suspects lines utilizing short, narrow cars (e.g. MBTA Blue Line, PATH, IRT, CTA) may not realize all the benefits of abandoning married pairs.

2. Some lines that have already made the shop and inventory investment in married pairs (e.g. MBTA Red Line, MNCRR) can not realize all the benefits.

3. My experiences strongly suggests that a different configuration, whether a single cab single or standard single, will not be fully exploited by certain transit agencies or commuter railroads simply because "new and different" is an incomprehendible term to them or their consulting engineers.

Furthermore, during the 1970's, standard singles for certain applications had so much redundant control logic and brake equipment added that their out-of-service failure rates approached that of two married pair cars! SEPTA carefully overhauled its 1974-76 vintage Silverliner IV commuter rail EMU cars starting in 1986. Availability is high among these newly overhauled cars, 96% less scheduled inspections. But it is no different for standard singles vs. married pairs: 96.5% vs. 96.8%. Part of the explanation is found in a "parts count" of the two configurations. The standard single has the large aforementioned collection of redundant devices not found on its predecessor Silverliner II and III cars, also singles. Another explanation is that maintenance managers preferentially repair married pairs before singles because one repair on a married pair returns two cars back to service.

V. CONCLUSIONS

There are two general areas of conclusions drawn from the preceding analysis. The first area concerns methodology and the second area concerns specific decision rules.

1. The analyses above lead one to believe each purchase of EMU cars and shops should be and can be analyzed separately. The wide range of each variable for each variable and the number of variables urge this. Table IV is a list of variables this analysis considered. Note the inclusion of shop costs, and of the most expensive item found in the shop: cars awaiting repair.

The methodology needed to make an analysis is not esoteric or complex. It is well understood, and widely used in industry. There is little reason to expend resources requiring elaborate proposal definition or voluminous reports. That data is unavailable is not accepted by this writer. Virtually all the data in this paper was developed by the staffs of commuter railways and rapid transit operations. It is likely many of these same organizations possess the resources to generate an analysis internally.

TABLE IV.
VARIABLES FOR INCLUSION IN ANALYSIS

Car length & weight
Car purchase costs for alternate configuration
"Redundant" component maintenance costs
- scheduled
- breakdown
- overhaul

Depreciation tax shield
Lease payments & schedule
Out of service failure rates
- MTBF/MDBF
- MTTR
- peak levels

Construction costs
- flat floor
- pit or raised rail
- hoist
- land
- maintenance

Train length in cars
Additional utilized passenger space per married pair
Discount rate & horizon
Transportation costs - N.E.C.

2. Despite the large number of variables and their ranges, general rules may be drawn. These rules are:

a. The smaller the car, the more married pairs or single cab singles make sense.

b. The larger the schedule requirement, the more married pairs or single cab singles make sense.

c. The more expensive land and construction is, the less married pairs make sense.

d. The longer the typical train set, the more married pairs make sense. The more off-peak service, the more the single configurations makes sense.

e. The more revenue producing space per car released by marriages, the more married pairs make sense.

f. The more the out-of-service failure rate is subject to sudden surges, the more singles of either configuration make sense. There are several situations that suggest the out-of-service failure rate may surge:

i. The cars represent a new technology.
ii. Harsh weather, especially winter weather, is a frequent.
iii. There is a liklihood of deficient, or deferred maintenance for whatever organizational reasons.

Footnotes

1. The following people provided their help. Of course, my conclusions are not necessarily the same as theirs:

   Richard Berk, Director of Equipment, PATCO
   David Casper and Fred S. Mylanayski,
   Chief & Senior Managers, Rail Equipment Engineering, SEPTA
   Richard Kirner, Chief Mechanical Officer,
   Metro North Commuter Railroad
   David Blizzard, Assistant Chief Mechanical Officer,
   New Jersey Transit Rail Operations
   George Hague, Director of Equipment, Regional Rail, SEPTA and his
   Manager of Administration, Russell Figeura
   Joseph Loughlin, General Superintendent,
   Broad Street Subway, SEPTA

2. Scheduled maintenance labor and material is greater for a single car than for a married pair car because a single has more equipment.

3. The discount rate is not viewed at the firm's cost-of-capital, but as an opportunity cost. Given the legal/institutional characteristics of public transit, the two expressions are not always equal. The correct discount rate for public finance is a matter of not only scholarly, but ideological, debate in the mass transit industry.

4. There are also married pairs built in 1969. These have not been heavy overhauled and are used for peak hour service.